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# Revision of methods to assess material efficiency of energy related products and potential requirements

*Environmental Footprint and Material Efficiency Support for Product Policy*

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# Abstract

The "Resource Efficiency Assessment of Product- REAPro" method[1] [2] has been developed to assess energy related products against a set of resource efficiency criteria, and to identify hot-spots and improvement potentials. The method has been applied and tested to various case-studies as: dishwashers, electronic displays, computers (notebook and tablets) and enterprise servers. These applications allowed to progressively refine the method from a scientifically perspective, but also to link the results to potentially new policy applications, including the development of new types of workable Ecodesign measures and Ecolabel criteria.

The present report summarizes the recent advancements of the REAPro method and the definition of innovative requirements. In particular, novel elements discussed in the report are:

- *Analysis of benefits of reused components*: The REAPro method only partially addressed the "reusability" concept (i.e. the potential full reuse of products at the EoL). However, it did not address the possibility that only certain key components (i.e. those having the highest residual value) could be collected from waste for the manufacturing of new products. This aspect has been addressed in a new method that allows to identify if, and to what extent, it is environmentally beneficial to reuse certain components for the remanufacturing of products (Chapter 2). In particular, it is observed that a product with reused components can still be environmentally convenient even if it has a higher energy consumption compared to brand-new products. The results of the method could be applied to build novel policy requirements, which allow higher energy efficiency thresholds for products that embody reused components.
- *Revision of the assessment of the index on recyclability*: based on comments received by stakeholders related to previous case-studies, the index on recyclability benefit rate of the REAPro method has been revised to clearly separate the environmental impacts of the WEEE recycling from the potential credits due to the secondary raw materials produced (Chapter 3).
- *Assessment of the disassemblability and dismantlability of key components*: design for disassembly of key components has been identified as a crucial aspect for the repair and recycling of the products. JRC has been working on developing suitable and verifiable requirements to assess *disassemblability and dismantlability* since 2012. These requirements have evolved, thanks to comments and suggestions from different stakeholders, and in particular from Market surveillance authorities of some Member States, which are in charge of verification of requirements. Two different types of requirements are presented and discussed in this report (Chapter 4): one based on numbers of disassembly steps necessary to disassemble certain components; and other based on criteria to grant the identification, access and extraction of key components for the product's recycling, including requirements on their fastening and the provision of relevant information for the end-of-life treatments.


[1] F Ardente, F Mathieux. Environmental assessment of the durability of energy-using products: method and application. Journal of Cleaner Production. 74(1), 2014, pp 62–73.

[2] F Ardente, F Mathieux. Identification and assessment of product's measures to improve resource efficiency: the case-study of an Energy using Product. Journal of Cleaner Production. 83, 2014, pp 126–141.

- *Recyclability of plastics*: recycling of plastics is one of the biggest challenges in the WEEE treatment and is addressed in Chapter 5 of this report. Criticalities in plastic recycling have been analysed. In particular, large number of different polymers, technological barriers for plastic sorting, content of additives (especially flame retardants), difficulties for the extraction of plastic parts, downcycling and low value of secondary materials are among the reasons of very low recycling rates for plastics in WEEE. The reports therefore propose some potential requirements based on plastic marking and provision of information. A novel index on the content of flame retardants in plastic parts is proposed. Together with requirements on dismantlability, these requirements could contribute to improve the recycling of plastics from WEEE.

At the time of the report (December 2016) several of the requirements above mentioned have been integrated and discussed in various policy proposals, as the Ecodesign requirements for electronic displays, enterprise servers and commercial refrigerating appliances, and Ecolabel criteria for computers and displays.

# 1 Introduction

The "Resource Efficiency Assessment of Product- REAPro" method has been developed to assess energy related products against a set of resource efficiency criteria, and to identify hot-spots and improvement potentials.

Within the current project "*Environmental Footprint and Material Efficiency Support for Product Policy*", the REAPro method has been applied and tested to various case-studies. These applications allowed to progressively refine the method and to link the results to EU product policies on Ecodesign and Ecolabel.

The present report is, therefore, intended to present evidences collected in the period 2013-2016 about the applications of the REAPro method and to illustrate modification of the method (including new indexes proposed) and the process of development of novel material efficiency criteria and requirements.

The report is subdivided in four parts.

Chapter 2 will investigate the assessment of the reuse of components in energy related products.

Chapter 3 will discuss the revision of the index on the recyclability benefit rate.

Chapter 4 will discuss the development of novel criteria for the disassemblability and dismantlability of key components in electric and electronic products.

Finally, Chapter 5 will present a comprehensive analysis of the recycling of plastics in WEEE and possible strategies to improve it.

# 2 Method for the environmental assessment of reused components in remanufactured products

The recent communication on "Closing the loop - An EU action plan for the Circular Economy" (COM 614, 2015) states that "once a product has been purchased, its lifetime can be extended through reuse and repair, hence avoiding wastage. The reuse and repairs sectors are labour-intensive and therefore contribute to the EU's jobs and social agenda". The communication also identifies that "better design can make products more durable or easier to repair, upgrade or remanufacture".

These principles have been also repealed by the Ecodesign Directive (2009/125/EC), which consider the "ease for reuse and recycling" as one of the parameters to be considered for evaluating the potential for improving the environmental aspects [EU, 2009].

This chapter aims at providing an analysis on how reuse and refurbishment could be assessed for the ecodesign of products and how products implementing measures could potentially promote them.

## 2.1 Ecodesign directive and reused/refurbished products

Implementing measures for energy related products have been enforced as European Regulations, setting ecodesign requirements for "placing on the market" or "putting into service" of products (see e.g. the [EC, 2013]). The Ecodesign directive defines these terms as [EU, 2009]:

- '*Placing on the market*' means making a product available for <u>the first time</u> on the Community market with a view to its distribution or use within the Community, whether for reward or free of charge and irrespective of the selling technique;
- '*Putting into service'* means <u>the first use</u> of a product for its intended purpose by an end-user in the Community;

In addition, the Ecodesign Directive defines [EU, 2009]:

- 'Reuse' as: "any operation by which a product or its components, having reached the end of <u>their first use</u>, are used for the same purpose for which they were conceived, including the continued use of a product which is returned to a collection point, distributor, recycler or manufacturer, as well as reuse of a product following refurbishment"
- 'end-of life' as: the state of a product having reached the end of <u>its first use</u> until its final disposal.

The waste directive additionally introduced the definition of the 'preparation for reuse' as [EU, 2008]:

- 'preparing for re-use' means checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing.

The term 'refurbishment' is not defined in the Ecodesign directive, neither in the WEEE directive (although mentioned in both the directives), furthermore the waste framework directive does not mention the term [EU, 2008].

A definition of "refurbishment" can be found in other sources as for example the standard BS 8887-211 (2012), defined as: "*process of a clean repaired product that can be brought back at least to the operational condition from the original point of manufacture with minor or nor cosmetic flaws. Note: refurbishment is synonym of reconditioning with the remarketing of computer equipment*". Refurbished or reconditioned products are expected to perform their intended role but the overall performance is likely to be inferior to that of the original model [BS, 2009].

Similarly, the BS 8887-211 (2012) defines "remanufacturing" as a "*process that brings a previously used product back to at least its original manufactured state in as-new condition, both cosmetically and functionally*". The term 'as-new' is defined in the standard BS 8887-2:2009 as "*product returned to a condition where it meets its original specification from the user's perspective. […] Performance after remanufacture is expected to be at least to the original performance specification*".

The standard EN 62309 defines "*qualified-as-good-as-new" as a part, which has been put into normal use on one or more occasions but differs from a second-hand part in that it is not just a re-sale, but it is also reconditioned and subjected to fully defined and documented quality checks prior to re-sale, such that it is in all dependability issues as good as new for the as-new designed life of the product. […] Qualified-as-good-as-new parts have been qualified as fit for purpose and as dependable as new parts for the as-new designed life of a product. The necessary level of documentation and quality checks depends on the application and the market requirements*" [EN 62309, 2004].

<u>According to these definitions, a product reused as a whole does not need to comply with requirements set afterwards by Ecodesign implementing measures. On the other hand, a product which is remanufactured using a number of reused components, should comply with the requirements as new product.</u> This is also confirmed by the European "The Blue Guide on the implementation of EU product rules – 2016" [EC, 2016]. According to this guide, "*products which have been repaired or exchanged (for example following a defect), without changing the original performance, purpose or type, are not to be considered as new products according to Union harmonisation legislation. Thus, such products do not need to undergo conformity assessment again, whether or not the original product was placed on the market before or after the legislation entered into force*[3]".

[3] In addition, it states that "such operations are often carried out by replacing a defective or worn item by a spare part, which is either identical, or at least similar, to the original part (for example modifications may have taken place due to technical progress, or discontinued production of the old part) or the entire identical unit" [EC, 2016].

On the other hand, "*a product, which has been subject to important changes or overhaul aiming to modify its original performance, purpose or type after it has been put into service […] must be considered as a new product. This has to be assessed on a case-by-case basis […]. Where a rebuilt or modified product is considered as a new product, it must comply with the provisions of the applicable legislation when it is made available or put into service. This has to be verified by applying the appropriate conformity assessment procedure laid down by the legislation in question. In particular, if the risk assessment leads to the conclusion that the nature of the hazard has changed or the level of risk has increased, then the modified product has to be treated as a new product*". The Blue Guide also mentions that "fully refurbished" products are assimilated to a new product[4] [EC, 2016].

The Union harmonisation legislation applies to "*newly manufactured products but also to used and second-hand products, including products resulting from the preparation for re-use of electrical or electronic waste, imported from a third country when they enter the Union market for the first time*", "*but not to such products already on the market*" [EC, 2016].

This has been similarly stated by the standard VDI 2343 on reused products mentioning that: "*under the interpretation principles of the guideline for the implementation of Directives based on the New Approach and the Global Approach (known as the Blue Guide), equipment is deemed to be placed on the market when it is provided for the first time, i. e. supplied to the single Community market […] after manufacturing with the objective of sale or use. […] These duties always apply to the manufacturers, i.e. those who place the product on the market for the first time. Re-use (re-use I) or e. g. reselling following repair (re-use II), do not give rise again to the obligations imposed*" e.g. by Ecodesign Directive. "*If, however, WEEE is modified so as to create a new product, those who place it on the market for the first time must also comply*" with e.g. Ecodesign provisions [VDI 2243, 2014].

In conclusion, fully refurbished products (or products which have been subject to important changes which changed the functionality) shall comply with the same requirements of new products, while this does not apply to repaired and second-hand products.

## 2.2 Reuse content: Modelling of potential benefits due to reused components

The partial or full remanufacturing/reuse of a product can produce some environmental benefits due to the avoided impacts for manufacturing and/or end-of-life (EoL) (i.e. avoided disposal).

On the other hand, reusing a product (or some of its components) could imply larger impacts during other life cycle phases as, for example, larger impacts during the operation due to a lower energy efficiency or the need of more frequent maintenance.

[4] However, the "Blue Guide" does not provide a definition of refurbished product.

Analogously to extending the lifetime of a product via e.g. repairing[5], there is a break-even point when it is not convenient anymore to reuse/refurbish a product but it is environmental preferable to discard it and substitute with a newer and more efficient one.

On the other side, companies dealing with the remanufacturing of products should comply with the same requirements as for new products. However, there would be still benefit in having reused/refurbished product although these had lower performances than new products (e.g. higher energy consumption during the operation).

### 2.2.1 Method for the assessment

This report aims at developing a method to calculate the potential benefits of reuse products and components, in a life cycle perspective, and assess until when reuse would be still beneficial with lower performances.

Finally, it could be possible to enforce reduced Ecodesign requirements for products with reused components, still having overall environmental benefits.

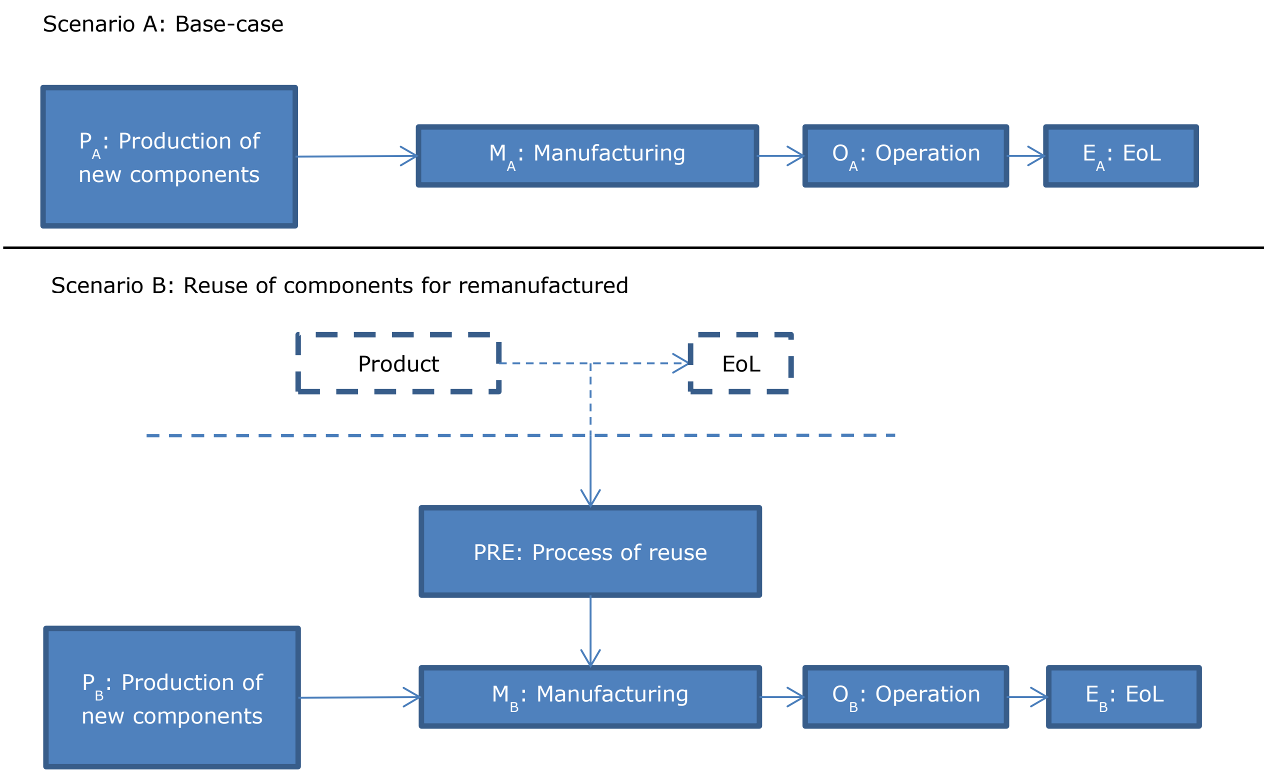


**Figure 2.1**. Systems boundaries: scenario A) Base-case; scenario B) Reuse of components for a remanufactured product

The assessment method is aiming at comparing two product systems: a base-case scenario of the product totally made by new components manufactured (product A) and

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[5] Ardente F., Mathieux F. Environmental assessment of durability of products: the case-study of energy using products.

the scenario with the product embodying reused components (product B). Figure 2.1 illustrates the system boundaries for the two scenarios. The potential environmental impact for each scenario is defined as:

***Formula 1:*** *Potential Environmental impact product A:* $= P_A + M_A + O_A + E_A$

***Formula 2:*** *Potential Environmental impact product B*[6]*:* $= P_B + PRE + M_B + O_B + E_B$

Where symbols are those described in Table 2.1.

**Table 2.1**: List of used symbols

| | |
|---|---|
| $P_A = \sum_{i}^{n_A} I_{i,j}$ | • $P_A$ = Environmental impacts due to the production of components for product A (scenario A)<br>• $I_{i,j}$ = environmental impact of the $i^{th}$ component for the impact category 'j' (per unit of mass)<br>• $n_A$ = number of components in product A (scenario A) |
| $P_B = \sum_{i}^{n_B} I_{i,j}$ | • $P_B$ = environmental impacts due to the production of new components for product B (scenario B)<br>• $I_{i,j}$ = environmental impact of the $i^{th}$ components for the impact category 'j' (per unit of mass)<br>• $n_B$ = number of components in product B (scenario B) |
| $PRE$ | Environmental impact due to process of reuse[7] of the components for the impact category 'j'. During this process, reused components are checked, tested, cleaned, repaired, and determined to be safe and fully functional, to be placed back on the market in their original use or in their upgrade state, without further processing. The potential environmental impact of this process is caused by the use of energy and ancillary materials. |
| $M_A$ ; $M_B$ | Environmental impact for the manufacturing of product A/B (scenario A ; B) for the impact category 'j' |
| $O_A = U_A + REP_A$ | • $O_A$ = Environmental impact for the operation of product A for the impact category 'j'.<br>• $U_A$ = Environmental impact due to use for the impact category 'j'<br>• $REP_A$ = Environmental impact due to reparation and maintenance during operation of product A for the impact category 'j' |
| $U_A = e_A \cdot I_e \cdot l_A$ | • $e_A$ = yearly energy consumption of product A due to use [kWh/year]<br>• $I_e$ = impact per unit of energy (impact category "j") [impact/kWh]<br>• $l_A$ = lifetime of product A [years] |
| $O_B = U_B + REP_B$ | • $O_B$ = Environmental impact for the operation of the product B for the impact category 'j'<br>• $U_B$ = Environmental Impact due to use for the impact category 'j' |

[6] System boundaries of the scenario B) are set considering that parts of waste products are disassembled and utilized for the remanufacturing of the product. The impacts due to the original manufacturing of these components are excluded. Analogously, potential credits due to the avoided EoL treatments of these reused components are not considered. These assumptions imply that reused parts do not have any environmental impact or credit deriving from the product system that generated them. Impacts of EoL of the products (e.g. the waste transport or the processing in a WEEE recycling plant) are included.

[7] Components derived from the EoL of another product system and used as input for the remanufacturing of a product (Scenario B)

| | |
|---|---|
| | • $REP_B$ = Environmental Impact due to reparation and maintenance during operation of product B for the impact category 'j' |
| $U_B = e_B \cdot I_e \cdot l_B$ | • $e_B$ = yearly energy consumption of product B due to use [kWh/year]<br>• $I_e$ = impact per unit of energy (impact category "j") [impact/kWh]<br>• $l_B$ = lifetime of product B [years] |
| $E_A$ ; $E_B$ | Environmental impact of the end-of-life (EoL) of the product A/B for the impact category 'j' |

The difference "Δ" among the two scenarios is:

***Formula 3:*** $\Delta = Impact_A - Impact_B = (P_A + M_A + O_A + E_A) - (P_B + PRE + M_B + O_B + E_B) = (P_A - P_B - PRE) + (M_A - M_B) + (O_A - O_B) + (E_A - E_B) = (P_A - P_B - PRE) + (M_A - M_B) + (U_A + REP_A - U_B - REP_B) + (E_A - E_B)$

Positive values of "Δ" represent the environmental benefit related to the reuse of components of the product, compared to the base-case manufacturing process. Negative values of "Δ" implies that the remanufactured product has higher life cycle impacts.

It is important to identify when, for a considered impact category, it results that ($\Delta \geq 0$), or:

***Formula 4:*** $(P_A - P_B - PRE) + (M_A - M_B) + (REP_A - REP_B) + (E_A - E_B) \geq (U_B - U_A)$

According to formula 4, environmental benefits can occur also when the remanufactured product (scenario B) consumes more energy than the base-case product (scenario A).

### 2.2.2. Additional assumptions for the calculation

In order to analyse the conditions when occurs that ($\Delta \geq 0$), some additional assumptions are introduced:

1. The products in the two scenarios have the same composition. Therefore the difference ($\Delta P_j = P_{A,j} - P_{B,j}$) amounts to the impacts of the components that are new in the base-case product while reused in scenario. This difference can be expressed as: $\Delta P_j = P_{A,j} - P_{B,j} = \sum_i^{n_{reused}} I_{i,j}$

Where:

- $n_{reused}$ = number of components reused by remanufacturing (scenario B);

- $I_{i,j}$ = Environmental impact (for the category 'j') of the $i^{th}$ component

2. The manufacturing process for scenario A and B are the same (i.e. $M_{A,j} = M_{B,j}$)[8].

3. The impacts generated by the end of life for both scenarios are the same: $E_{A,j} = E_{B,j}$

As a result, the previous formula 4 becomes:

**Formula 5:** $$(\Delta P_j - PRE_j) + (REP_{A,j} - REP_{B,j}) \geq (U_{B,j} - U_{A,j})$$

Furthermore, expressing:

- $(U_{B,j} = \delta_j \cdot U_{A,j})$ being $(\delta_j \geq 0)$, i.e. the impact due to use generated by a remanufactured product (scenario B) is proportional to the impacts of a new product (scenario A).

The previous formula becomes:

**Formula 6:** $$(\Delta P_j - PRE_j) + (REP_{A,j} - REP_{B,j}) \geq U_{A,j} (\delta_j - 1)$$

Or analogously:

**Formula 7:** $$\delta_j \leq 1 + \frac{(\Delta P_j - PRE_j) + (REP_{A,j} - REP_{B,j})}{U_{A,j}}$$

In conclusion, there is an environmental benefit in reusing components in a remanufactured product when the condition set in formula 7 is satisfied.

Assuming that the maintenance of the two products is the same or very similar, it follows that $(REP_A \approx REP_B)$ and equation 7) can be written as:

**Formula 8:** $$\delta_j \leq 1 + \frac{(\Delta P_j - PRE_j)}{U_{A,j}}$$

From formula 8 it follows that, if the remanufactured product has higher impacts during the operation $(\delta_j > 1)$, environmental benefits can still occur when $(\Delta P_j > PRE_j)$, meaning when the impacts due to the production of components that are reused are greater than the impacts due to the process of reuse, for the considered impact category "j".

## 2.3 Reusability Benefit rate: revision of the index

As described in [Ardente and Mathieux, 2012], the REAPro method includes a set of indicators useful to assess the environmental benefits of potentially reusable components of a product. In particular, the Reusability Benefit rate ($R'_{use,j}$) is defined as (formula adapted from [Ardente and Mathieux, 2012] with the symbols in Table 1.1):

[8] The manufacturing process is independent from the origin of the components (brand new or reused).

***Formula 9:*** $$R'_{use,j} = \frac{\sum_i (I_{i,j} + D_{i,j} - PRE_{i,j})}{P_j + M_j + O_j + E_j} \cdot 100$$

Where:

- $R'_{use,j}$ = Reusability Benefit rate for the $j^{th}$ impact category [%]
- $I_{i,j}$ = Environmental impact of the $i^{th}$ reusable component for the impact category 'j';
- $D_{i,j}$ = Environmental impact of the avoided disposal of the $i^{th}$ reusable component for the impact category 'j';
- $PRE_{i,j}$ = Environmental impact due to the reuse/refurbishment of component '$i^{th}$' for the impact category 'j';
- $P_j$ = Environmental impact of the production of components in the product for the impact category 'j';
- $M_j$ = Environmental impact of the manufacturing of the product for the impact category 'j';
- $O_j$ = Environmental impact of the operation of the product for the impact category 'j';
- $E_j$ = Environmental impact of the end-of-life of the product for the impact category 'j'

The application of this formula poses some problems, as:

- the benefits due to a reusable component are assumed to be equal to the overall impacts due to the production and manufacturing of the component. This can cause an over-estimation of the benefits assuming that, anyway, a reused component is affected by wear and/or obsolescence. These aspects could be captured by the introduction of a downcycling factor for reusable components, analogously to that introduced for recyclable materials.

- the benefits due to a reused component should also include the avoided (or better, the delayed) EoL treatments. However, this implies the assumption of an alternative EoL scenario, where the component is being discarded instead than reused. These EoL treatments could imply, for example, recycling and/or recovery, with additional assumptions about potential impacts/benefits. The formula can be therefore simplified, assuming to neglect these benefits (conservative assumption). Analogously, the denominator of the formula account for all the life cycle impacts of the products. This includes also the treatment for EoL. As previously discussed, also in this case it would be necessary to assume some EoL and account for impacts due to recycling/recovery of components in the base-case scenario. However, in order to account for the impacts/benefits of reusable product without accounting for other impacts/benefits due to recycling/recovery, it is suggested to simplify the formula excluding the term "E" from the denominator.

The Reusability Benefit rate is therefore revised as following:

$$\textbf{\textit{Formula 10:}} \qquad R'_{use,j} = \frac{\sum_i (k_i \cdot I_{i,j} - PRE_{i,j})}{P_j + M_j + O_j} \cdot 100$$

Where, in addition to previous symbols:

- $k_i$ = downcycling factor for reusable component "i" [adimensional].

The factor ($k_i$) represents the downcycling factor for reusable components. It accounts for the potential loss of performance due for example to wear or obsolescence. This downcycling factor allows also accounting for the potential reuse of components as spare parts for products. This factor could be estimated for example as:

- the ratio between the price of the reused component and the price of the component when new;

- or the ratio among the lifetime of the reused component and the lifetime of the component when new, whichever is lower.

## 2.4 Ecodesign requirements for remanufactured products

Ecodesign implementing measures (IM) for energy related products generally set thresholds of the energy consumption of the product (per cycle, per year, etc.). For example, the IM for notebook computer established that, "*starting from 1st January 2016, a notebook computer with at least one discrete graphics card shall have an annual total energy consumption ($E_{TEC}$) not exceeding 112,00* [kWh/year]" [EC, 2013].

Following previous notation, the $E_{TEC}$ value of this IM would represent the previously introduced factor "$e_A$" of Table 2.1 (yearly energy consumption of product A).

Considering the definition of "δ" as: $(U_{B,j} = \delta_j \cdot U_{A,j})$, this can be expressed as:

$$\textbf{\textit{Formula 11:}} \qquad U_{B,j} = e_B \cdot I_e \cdot l_B = \delta_j \cdot e_A \cdot I_e \cdot l_A$$

Assuming that the two products "A" and "B" will have the same expected lifetime[9], it becomes:

$$\textbf{\textit{Formula 12:}} \qquad e_B = \delta_j \times e_A$$

Considering the condition set in (formula 8), a potential requirement for a remanufactured product could be set as:

$$\textbf{\textit{Formula 13:}} \qquad E_{TEC,\ remanufactured} = \delta_j \times E_{TEC}$$

This means that policies could set IMs on energy efficiency thresholds differentiated among new products and remanufactured products (i.e. products including reused components sold as-new). For remanufactured products, higher thresholds regarding the

[9] This assumption is plausible, considering that remanufactured products are sold as-new, with the same expected lifetime of the new product.

total energy consumptions could be accepted, as long as they still allow higher lifecycle benefits.

An example of generic requirement on products with reused components is following presented[10].

**Requirement for reuse of components in remanufactured products**

Definitions:

- 'Reuse' means any operation by which a product or its components, having reached the end of their first use, are used for the same purpose for which they were conceived, including the continued use of a product which is returned to a collection point, distributor, recycler or manufacturer, as well as reuse of a product following remanufacturing.
- 'Remanufacturing' means a process that brings back a product or some of its components to their original manufactured state, in 'as-new' condition, both cosmetically and functionally.

Requirement:

Assumed that the annual total energy consumption of the product shall not exceed the value "$E_{TEC}$" [kWh/year], the annual total energy consumption of remanufactured products with reused components ($X_1$, $X_2$, $X_3$…,) shall not exceed the value: $E_{TEC,\ remanufactured}$ (in [kWh/year]).

The value of $E_{TEC,\ remanufactured}$ would be calculated according to previous formulas, based on the components ($X_1$, $X_2$, $X_3$, …) reused in remanufactured product.

This type of requirement represents an innovative way of promoting the reuse via product measures[11]. It is expected that: $E_{TEC,\ remanufactured} > E_{TEC}$ meaning that it is allowed

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[10] This exemplary requirement has been developed based on the analysis of material efficiency aspects for enterprise servers.

[11] A similar approach has been used in EU policies for other aspects, as the content of materials with high environmental impacts. For example, the implementing measure on Ecodesign of "air conditioners and air fans" established that [EC, 2012]: "bonus is proposed under the ecodesign requirements to steer the market towards the use of refrigerants with reduced harmful impact on the environment. The bonus will lead to lower minimum energy efficiency requirements for appliances using low- global warming potential (GWP) refrigerants".

that a remanufactured product will have a higher annual total energy consumption still granting overall environmental benefits (namely $\Delta > 0$).

It this way, this measure will not represent a burden for manufacturers producing new products, since they will have to comply with the thresholds "$E_{TEC}$". On the other hand, manufacturers could be incentivised in producing remanufactured products, since these could comply with a higher $E_{TEC,\ remanufactured}$ thresholds.

A similar approach could be also applied to the Energy labelling of ErP. In this case, a "bonus" could be foreseen for products with reused components. However, such approach is only theoretical and need further investigation/research.

For the verification of such measures, manufacturers should provide evidences on reused components (e.g. documentation on the original products where the components have been used the first time and their successive use in remanufactured products). Traceability of reused components in the market is therefore essential.

# 3 Revision of method for the environmental assessment of recyclability

## 3.1 Introduction

Within the project "Integration of resource efficiency and waste management criteria in European product policies – Second phase", a series of environmental indicators concerning the EoL of ErP has been developed. These included, among the others, the Recyclability Benefit Rate (RBR). The RBR aims at accounting of the potential benefits of recycling some materials and components for WEEE, compared to the overall product life-cycle, as (adapted from Ardente and Mathieux (2012)):

***Formula 14:*** $$RBR_{\,i} = \frac{B}{LCA} = \frac{\sum_n k_n \cdot P'_n - \sum_n R_n + \sum_n E'_n}{P+M+O+E} \cdot 100$$

Where:

- RBR = Recyclability benefit rate for the generic impact category "i" [%];
- B = net benefits of potential recycling of the product [impacts];
- LCA = life cycle impacts of the product [impacts];
- $k_n$ = downcycling factor of recycled material "n" [adimensional];
- P= impacts of primary materials used for the production of the product [impacts];
- $P'_n$ = benefits in terms of avoided primary materials due to the recycling of material "n" [impacts];
- M= overall impact of manufacturing the product [impacts];
- R = overall impacts due to the recycling of materials [impacts];
- O = overall impact due to the operation of the product [impacts];
- E = overall impact of EoL of the product [impacts];
- $E'_n$ = avoided impacts at EoL due to the recycling of material "n" (due e.g. to avoided disposal) [impacts];

## 3.2 Revision of the Recyclability Benefit rate

The application of this formula poses a main problem, since the terms on EoL are both in the numerator and denominator of the formula. This could have the effect of accounting for the benefits of EoL recycling in both numerator and denominator, and distorting the result of the index. Therefore, for the calculation of the index it has been assumed to compare the benefits of the potential recycling of materials (in the numerator) compared to the life cycle impacts for a base-case scenario (when the product is not recycled, but landfilled).

In addition, the numerator includes the impact "R" due to the recycling. This term accounts for all the impacts related to the treatment of the waste, the sorting of different recyclable materials and their further processing for the secondary materials production (including impacts of the transport during these different phases). However, for the clarity of the formula, these terms could be separated to differentiate among what is related to the product waste recycling, from what is occurring afterwards to each single material.

For these reasons, it is suggested to revise the formula of the RBR as following:

$$\textbf{Formula 15:} \qquad RBR_i^* = \frac{\sum_n k_n \cdot P'_n - R_1 - \sum_n R_{2,n}}{P+M+O} \cdot 100$$

Where, symbols not described before are (figure 3.1):

- $RBR^*$ = revised Recyclability benefit rate [%]
- $R_1$ = impacts due to the treatment of the waste product in the recycling plant [impacts];
- $R_{2,n}$ = impacts due to the recycling of material "n" for the production of secondary material [impacts].

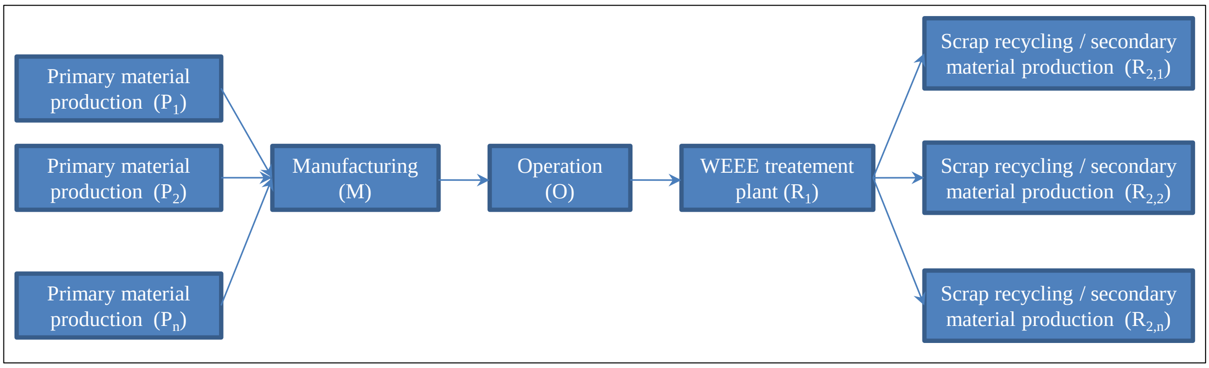


**Figure 3.1**. System boundaries for the revised "Recyclability benefit rate" index

The formula therefore omitted the benefits in terms of avoided disposal (in the numerator) and impact of EoL in the denominator. Moreover, the new formula distinguishes between the impacts "$R_2$" to process the waste, from the impacts "$R_1$" due to the production of secondary raw materials from recycled materials.

The term "$R_1$" includes:

- impact due to the transports of the waste[12]

- impact of pre-processing[13]

- impact of shredding [14]

- impact of sorting [15]

[12] This accounts for all the transport occurring from the final user up to the recycling facility

[13] This could include, for example, the use of electricity to run machine tools used for manual disassembly.

[14] This could include, for example, the use of electricity and auxiliary materials needed to run the shredders, and emission of dusts from the machines.

[15] This could include, for example, the electricity used by magnetic separators and waste waters produced for the density separators of plastics.

The term "$R_{1,n}$" includes instead all the impacts due to the processing of the materials, which have been sorted in the waste treatment in the plant. These impacts are dependent on the type of material "n", as: the transport of the scrap from the waste recycling facility to the successive treatment plant; the impacts of processing the scraps (e.g. further fine shredding); impacts of further treatment of the scraps (e.g. due to sorting, melting, refining, extruding, smelting) up to the production of the secondary raw material.

# 4 Design for disassembly and dismantling: identification and verification of workable requirements

Disassembly[16] and dismantling[17] of key components in products are often identified as necessary to enhance re-use and repair, but also to maximize material efficiency of recycling. This sections aims at sharing some methodological advancements concerning the analysis of disassembly of product groups (section 4.1) and at discussing the importance of the formulation of disassembly / dismantling requirements in the context of Ecodesign Directive (Section 4.2).

## 4.1 Analysis of disassembly steps to identify potential requirements

The first step to develop material efficiency criteria is to identify relevant product groups. Relevant product groups are those in good time with the revision the EU Ecodesign Directive and the EU Ecolabel, but also for environmental reasons, including high volume of sales but also content of certain materials as precious metals, copper and other materials targeted as critical raw materials by the EC (European Commission 2013).

Once the product group to be assessed is defined, the next step is to identify critical components for material efficiency aspects (e.g. components that are crucial for repair operations or for their content of valuable materials). The identification of critical components can be based on the bill of materials (BoM), the EoL management of the product, and the analysis of disassembly of the product. Data about the BoM allows identifying components that contain hazardous substances that require specific treatment operations at their EoL, and also other materials relevant for their potential recovery as critical raw materials. Information on the BoM helps understand the materials used in greater amounts in products, but most importantly it allows to develop quantitative assessments about the potential environmental impacts and environmental benefits associated to potential requirements enhancing reuse and recycling.

Information about the EoL management of products allows finding possible burdens for EoL treatments but especially identifying the difficulties that refurbishing and recycling companies face at their facilities when treating those products. EoL information also allows understanding better where and how product's improvements could be implemented.

The analysis of disassembly of the product helps to identify relevant components and fastening techniques. Components can be identified by disassembling several exemplary products and also from discussion with diverse stakeholders (i.e. refurbishing operators, waste treatment and recycling companies). If exemplary products available to disassemble are limited, Design for Disassembly (DfD) information can also be gathered from audio-visual material available in internet from amateur and non-professionals as well as from specialised websites, as Newpower99, Fixez, Directfix and iFixit, which

[16] Disassembly is a reversal process in which a product is separated into its components and/or sub-assemblies by non-destructive or semi-destructive operations which only damage the connectors/fasteners [Vanegas et al., 2016].

[17] If the product separation process is irreversible, this process is called dismantling [Vanegas et al., 2016].

provide information and commercialise some disassembly tools to facilitate the repair of electrical and electronic products (directfix 2016; fixez 2016; ifixit 2016; newpower99 2016). Audio-visual material is generally recorded to facilitate duplication to anybody else doing the same operation independently, thus it illustrates in detail the step-by-step instructions to repair and replace certain components in products. The greatest advantages of videos is that they are efficient and effective compared to the purchase of models which can be very costly (e.g. the price of a PC-tablet ranges from 120 to 600 €), and the availability of information of many diverse models within product groups and sub-groups which helps understand the most common design features used by manufacturers. One possible limitation is the availability of videos of less commercialised models.

Information about disassembly is used to develop a series of alphabetical disassembly codes that facilitate the identification of common design practices. Alphabetical codes (from A to F) to synthetize information about the disassembly steps and tools can be developed. In some cases, the number of additional steps required to extract certain components can be further described using numerical values which can be placed before or/and after the disassembly code. Table 4.1 shows a fictitious example to illustrate how disassembly codes and steps could be defined.

**Table 4.1.** Disassembly codes and steps to separate batteries in computers.

| Disassembly code | Disassembly steps | | Tools |
|---|---|---|---|
| | Description | Number | |
| A | Spring-loaded release | 1 | none |
| B | Remove base cover, unplug and unscrew battery packs | 3 | Screwdriver |
| 1+B | Steps described in B plus one pre-step (e.g. remove connector cover on the side) | 4 | Screwdriver |
| 1+B+1 | Steps described in B plus one pre-step (e.g. remove connector shell on the side) and one post-step (e.g. unplug additional cables). | 5 | Screwdriver |
| C | Remove base cover, remove adhesive, unscrew and unplug battery pack | 4 | Screwdriver |
| 2+C | Steps described in C plus two pre-steps (e.g. unplug battery and remove HDD unit). | 6 | Screwdriver |
| D | Remove base cover, connectors, lift tape, unscrew and unplug battery pack, and pull without disconnecting speakers cables | 6 | Screwdriver |

For example, the disassembly code B means that to extract battery packs, first the base cover needs to be removed, and then the battery has to be unplugged and unscrewed. Code 1+B means that before removing the base cover, an additional step as a side connector cover needs to be pulled out.

Although it seems theoretically possible to develop disassembly codes applicable for all product groups, in reality products and product groups are designed so differently that this makes it challenging. As results disassembly codes need to be developed for each product group. When defined for a product group, they become useful as they help synthetize the number of disassembly steps and tools needed to separate a component. They help group and rank the units to understand the most frequent design option adopted by manufacturers which help identifying workable DfD requirements in EU product policies.

An example of how disassembly criteria could be integrated in a product requirement is following illustrated[18].

**Requirement on design for disassembly and replacement of batteries in a product**

The battery shall be easy to extract by one person (either the user or repair service provider). The following specific requirements apply:

- Batteries shall not be glued or welded into a product;
- It shall be possible for the user to extract the battery without tools;
- It shall be possible to extract the battery in a maximum of three steps using a screwdriver;
- It shall be possible to extract the battery in a maximum of four steps using a screwdriver and spudger;
- Simple instructions about how the battery packs are to be removed shall be marked on the base cover of the product.

## 4.2 Proposal of verifiable requirements concerning in the context of Ecodesign Directive

In order to always make possible disassembly and dismantling at repair or recycling plants, products need some DfD features. This has been demonstrated by JRC for various product groups, as for example electronic displays [Ardente and Mathieux, 2012b], enterprise servers [Talens-Peiro et Ardente, 2015] and commercial refrigerating appliances [Ardente et al., 2015].

A good way to ensure that all products put on the market present these DfD features would be to set DfD requirements in the context of the Ecodesign Directive. This would be in line with the EC's commitment to "promote reparability, upgradability, durability, and recyclability of products by developing product requirements relevant to the circular economy in its future work under the Ecodesign Directive" [EC, 2015a].

Already back in 2012, discussions on potential DfD requirement took place during formal consultation of stakeholders in the context of the Ecodesign Directive. For example, a potential requirement was proposed for the "*Electronic display*" product group and this is

[18] This criterion has been developed based on the analysis of Ecolabel criteria for computers.

presented in the box below. This requirement was proposed in a JRC report [Ardente and Mathieux, 2012b] and discussed during the meeting of the consultation forum under Ecodesign Directive for televisions and displays, on October 8th 2012.

**Requirement on design for disassembly of key parts in the LCD-TV**

The time for the extraction of fluorescent lamps and LCD screen larger than 100 cm2 embedded in the LCD-TV (as performed by professionally trained personnel using tools usually available to them) shall be less than 240 seconds.

This initial proposal of mandatory DfD requirement targets a maximum time for dismantling of key components in the display (because of their content of hazardous substances or their value), in order to make economically viable the manual dismantling process, which brings the highest material efficiency during recycling. Such proposal has been further refined in another JRC report published in 2013 [Ardente et al., 2013]. However, such requirement was not adopted by Ecodesign regulations because of the absence of standardized method to measure this time for dismantling. It can be noted that a recent JRC technical report proposes some initial answers to this fundamental limitation [Recchioni et al., 2016].

Because of the relevance of DfD features, there were several requests from different stakeholders to develop further such requirements since 2012. Hence, the JRC developed some other potential DfD requirements, still considering the absence of dedicated measurement standards. For example, the following DfD requirement was developed and discussed during the Consultation Forum on the 2nd July 2014 on the Ecodesign regulation for "*Commercial Refrigerating appliances".*

**End-of-life requirement for refrigerated commercial display cabinets.**

Manufacturers shall ensure that refrigerated commercial display cabinets are designed so that the following electric and electronic components (when present):

• printed circuit boards (larger than 10 $cm^2$);

• electrolyte capacitors containing substances of concern (height > 25 mm, diameter > 25 mm or proportionately similar volume).

• Liquid crystal displays (LCD; larger than 100 $cm^2$);

• mercury containing switches or backlighting lamps;

• gas discharged lamps;

• batteries.

can be:

• easily identified. This can be ensured, for instance, by making the components directly visible to the recycling operator after removing the external covers or lids. If the components to be extracted are not directly visible (once the external covers or lids are removed), the appliances shall be marked to facilitate their location (e.g. by using, in the back panel of the appliance, labels, sketches, drawings or pictures with the location of these components).

• easily accessed. This can be ensured, for instance, by designing the appliances so that the targeted components are accessible in few dismantling steps after removing the external covers or lids of the appliance.

• extracted for recycling using only standard tools. These components shall be easy to separate manually (avoiding glued or welded parts). Manufacturers shall use only 'easy-to-disassemble' fasteners (screws and snap-fits) for all the dismantling steps leading to the extraction of the above listed.

Upon request, manufacturers shall provide technical evidence of all the points above to the market surveillance authority and recyclers.

This requirement proposal aimed at formalizing better what is meant by dismantlability / disassemblability, and defines some sub-features such as identifiability, accessibility and extractability. The proposal was in general well received by stakeholders during the Consultation Forum. However, some Member States questioned about its verifiability by Market Surveillance Authorities.

Hence, JRC conducted in 2014 and 2015 some extensive, bi-lateral discussions with Market Surveillance Authorities of some Member States and one NGO on the basis of the previous DfD requirement proposal. This work was useful to understand how a requirement can be verified or not. Some revised version of DfD requirements for electronic displays and commercial refrigerating appliances were also produced and agreed by consulted parties. This work conducted for example the JRC and DG ENER to propose the following DfD requirement in the Consultation Forum on the 10th December 2014 on the TV review and electronic displays regulations.

**Requirement on design for recovery of electronic displays**

Manufacturers shall ensure that electronic displays are designed so that the following four types of components (when present) can be dismantled:

• printed circuit boards assembly (larger than 10 $cm^2$);

• thin-film-transistor liquid-crystal display (larger than 100 $cm^2$);

• PMMA board;

• mercury containing backlighting lamps.

This shall be ensured by documenting the sequence of dismantling operations needed to access the targeted components, including for each of these operations: type of operation, type and number of fastening technique(s) to be unlocked, and tool(s) required.

This requirement reposes on the need for manufacturers to document the sequence of dismantling operations, documentation that can be verified by Market Surveillance Authorities. It is assumed that such requirement will be an incentive for manufacturers to systematically use fast and reversible fastening techniques for targeted components.

Work is on-going to further improve such type of DfD requirement, with the aim to limit design practices that significantly negatively impact the recycling processes (e.g. permanent fixation between some components), still keeping them verifiable by Market Surveillance Authorities.

In the future, more DfD requirements with quantitative targets could be developed, for example building on the recent proposal of the eDiM method [Vanegas et al., 2016]. Moreover, DfD requirements will be enhanced by the standardization deliverables to be issued in the context of the standardization mandate M/543, which will focus among the others on the measurement of the "*ability to access or remove certain components, consumables or assemblies from products to facilitate repair or remanufacture or reuse*" and "*ability to access or remove certain components or assemblies from products to facilitate their extraction at the end-of-life for ease of treatment and recycling*" [EC, 2015b].

# 5 Recyclability of plastics, marking and labelling

## 5.1 Introduction

There are many benefits to be gained by the improved recycling of plastics [BPF, 2015]:

- Provides a sustainable source of raw materials to industry;
- Greatly reduces the environmental impact of plastic-rich products;
- Minimises the amount of plastic being sent to landfill sites;
- Avoids the consumption of the Earth's oil stocks and other resources;
- Consumes less energy than producing new, virgin polymers.

Although in theory plastics are all perfectly recyclable, in practice the recyclability of plastics is generally very low – almost non-existent (because the recycling system does not exist) [EN TS 16524, 2013]. "*Products consisting mainly of plastic have a very low recyclability rate in practice and it is all the lower when different plastics are combined in the same product*" [EN TS 16524, 2013].

The European Commission in 2013 observed that only a small fraction of plastic waste is at present recycled [EC, 2013b]. The enhanced recycling of plastics would contribute to the aims of the Roadmap to a Resource Efficient Europe adopted in 2011[19] and help to reduce greenhouse gas emissions and imports of raw materials and fossil fuels. Appropriately designed measures to recycle plastic can also improve competitiveness and create new economic activities and jobs [EC, 2013b]. Recycling of plastics, in particular, has been identified as one of the priority areas of the Circular Economy Action Plan of the European Commission [EC, 2015a].

Plastic recycling poses various problems as [Peeters et al., 2014; Elo, 2013]:

- The lack of process capable of performing plastic sorting and separation
- Plastic can be recycled roughly a limited number of times (three to four); then the plastic is worn out and of a poor quality;
- Complexity of the plastic mix (up to 300 different types of plastics in WEEE). This makes difficult to separate plastics from each other and expensive to recycle;
- Plastics can contain several additives which degrade the virgin plastic;
- Plastic can be reinforced or mixed with metals and other non-plastics, which degrade the plastic when recycled.
- Most plastics type are only present in relatively small flow amounts, which makes difficult to achieve the required economies of scale for advanced recycling operations.

The importance of plastic recycling but also the challenges faced by plastic recyclers and recyclers of various end-of-life products have been recently highlighted by representatives of the recycling sector [Recycling Associations, 2016; EERA, 2016].

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[19] COM(2011) 571.

In this context, design features of parts made of plastics can enhance further recycling. These are described in the sections below.

### 5.1.1 Additives and plastic recyclability

Flame retardants (FRs) are chemical additives added into plastics to avoid potential internally and externally initiated ignitions.

Worldwide 241 million tons/year of plastics are produced whose 45.9 million tons/year in EU [Tange, 2015]. FRs are largely used into EEE. The average share of plastics applied in WEEE is 5.5% (in weight) and 26% of all housing plastics applied in WEEE contain FRs [Tange, 2015]. A detail of FR consumption in the EU is showed in Figure 5.1.

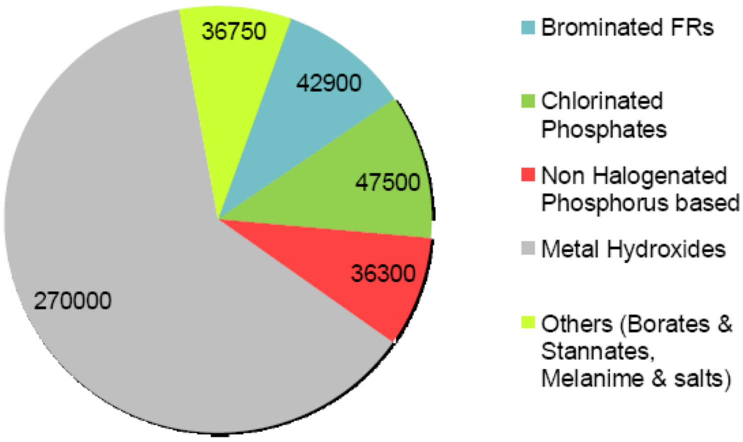


Figure 5.1. European Union consumption of flame retardants in 2008 (in metric tons) [Tange, 2015].

Analysing in detail some specific product groups, Peeters et al. (2014) observed that the share of TVs at the recycling plant containing phosphorous flame retardants (PFRs) in the housings was 31%, while the share of Brominated Flame Retardants (BFRs) was around 18% [Peeters et al., 2014]

FRs can reduce the recyclability of plastic parts. The presence of additives can reduce the mechanical properties of the materials, requiring additional treatments and additives to compensate for the degradation of such properties, as well as reduce the value of the materials in the market, and consequently the economic feasibility of recycling [Dawson and Landry, 2005].

Some FRs have high toxicity and for this reason have been regulated. In particular, the use of certain brominated flame retardants (BFRs) is being regulated in diverse pieces of legislation. For instance, the directive 2011/65/EU on the restriction of the use of certain hazardous substances in electrical and electronic products (RoHS) established that member states shall ensure that new electrical and electronic equipment put on the market does not contain substances as polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) [EU, 2011]. In addition, the directive

2012/19/EU on waste electrical and electronic equipment (WEEE) states in Annex VII that plastic containing BFR have to be removed from any separately collected WEEE [EU, 2012]. Recycled plastics coming from flows of WEEE hence face challenges when they are re-introduced in new electr(on)ic equipment. This issue is addressed in the Circular Economy Action Plan that states: "*The promotion of non-toxic material cycles and better tracking of chemicals of concern in products will facilitate recycling and improve the uptake of secondary raw materials. The interaction of legislations on waste, products and chemicals must be assessed in the context of a circular economy in order to decide the right course of action at EU level to address the presence of substances of concern, limit unnecessary burden for recyclers and facilitate the traceability and risk management of chemicals in the recycling process*" [EC, 2015a]. Analysis and policy options to address these issues should be proposed in 2017.

According to some scientific studies, many BRF (especially those restricted by the RoHS Directive) have been phased out in electronic displays [Peeters et al., 2014]. However, there are evidences that other BFR currently not regulated, could have severe toxic effects as the hexabromocyclododecane (HBCD) is a persistent bioaccumulative and toxic substance [ECHA, 2008].

In addition the need to continue using flame retardants has been questioned for some EEE as e.g. for televisions, being that internally-initiate fires has become more unlikely as result of the use of lower voltages (200 V) and power levels than older TVs using cathode ray tube technology (15,000 to 25,000 V); and improvements in lightness and thinnest have influenced the positioning of TVs, usually hanged in the wall now, thus external ignition sources TVs are unlikely source of ignition [Blum, 2014].

Several projects to recycle plastics with FR have been promoted and/or contributed by the European Flame Retardant Association (EFRA) including [Tange, 2015]:

- Development of analytical / identification and sorting techniques;

- Research on mechanical treatments for the recycling of plastics with FRs, and chemical recycling to separate plastics from PBDEs and HBCD;

- Analysis of treatments in precious metal smelters

- Analysis of energy recovery by pyrolysis – gasification of FR plastics

- Analysis of energy recovery by incineration of FR plastics and analysis of corrosion problems by halogens in incinerators.

Some proactive manufacturers also decided, when technically feasible, to progressively phase out all BFRs, polyvinyl chloride (PVC), and phthalates (used as plasticizers) to meet market demands and customer expectations [HP, 2014]. For some specific applications technical issues still exist as [HP, 2014]:

– Electrical performance issues above 1 GHz in Halogen-free printed circuit boards due to

- Dielectric loss
- Unpredictability of technical performance

– Safety issues in high temperature areas

- Availability issues for environmentally-preferable alternatives

- Transition to new substances for high performance products with long life- cycles

- Ability to maintain high recycled content as substances are restricted

These critical issues could be overcome, for example, by setting some specific exemptions in the legislation [HP, 2014].

EFRA also highlighted the need of some changes in the regulations to promote recyclability of plastics as, for example, changing the accounting of the recycling rate in the WEEE and the End-of-life of vehicles (ELV) Directive (2000/53/EC). Currently these rates are based on the input side (i.e. assuming that 1 tonne of separated waste corresponds to 1 tonne recycled, with 100% recycling rate). Suggestion by EFRA is to move towards the "output based calculation" (i.e. from 1 tonne of separated waste, 600 kg are recycled and 400 kg incinerated, the recycling rate should be 60%) [Tange, 2015].

At the international level, the United Nations (UN) launched the Basel Convention on the control of transboundary movements of hazardous wastes[20], which obliges its parties to ensure that hazardous and other wastes are managed and disposed of in an environmentally sound manner. The UN also launched the 'Stockholm Convention[21]' on Persistant Organic Pollutants (POPs), which aims to eliminate or restrict the production and use of POPs. The two convention focuses, among the others, to hazardous POP including some BFRs as [Lange, 2015]: Hexa-BDE and Hepta-BDE present in commercial Octa-BDE; Tetra-BDE and Penta-BDE present in commercial Penta-BDE; and HBCD. A low POP limit is provisionally recommended: any waste containing POP substance above that limit has to be treated such that the POP substance is destroyed in an environmentally sound manner (e.g. incineration). No recycling allowed above low POP limit. According to the European legislation on POP (Regulation 850/2004) the POP limit was of 1,000 ppm for the sum of POP BDEs. Currently some option limits are discussed for HBCD [Lange, 2015]. EFRA is advocating the need to align POP limits for HBCD with the EU REACH Regulation, and to adopt a 1,000 ppm limit as a statistically measurable and enforceable limit. The adoption of too restrictive limits (e.g. 10 ppm of HBCD for unintentional trace contamination thresholds) would stop the recycling of plastics containing "traces" of bromine [Lange, 2015]: as no 100% separation is possible, shredding plastics from automotive and EEE will not be possible.

## 5.2 Methods for plastic sorting

The different stages of sorting plastic waste include [Elo et. al, 2009]:

· Separate plastics and non-plastics

· Separate rigid plastic components and non-rigid plastic components

[20] http://www.basel.int (accessed February 2016)
[21] http://chm.pops.int (accessed February 2016)

· Separate coloured plastics and non-coloured plastics

· Sort the different plastic types

Density sorting of plastics (via sink-float techniques) is currently the easiest and still most adopted sorting systems for shredded plastics [Peeters et al., 2014]. Different plastics are separated according to their different density thanks to water or air separators.

For example, the IEC/TR 62635 considers the following average values for the recycling rates of polymers after non selective shredding with other materials:

- ABS (without additives): 74%
- PP without additives, PP-EPDM, PP with glass fibres: 90%
- PE (without additives): 90%
- HI-PS (without additives): 83%.

FRs, or other substances contained in a plastic parts are likely to penalize the recycling. For example, in all the other cases than those listed (i.e. other polymers or polymers with additives as flame retardants and fillers), the IEC/TR 62635 assumes 0% recyclability. Similarly, the EN TS 16524, 2013 consider a recycling rate of 0% for parts made of several plastics, for dual parts or metallic parts encased with plastics. Plastics with additives have, in fact, density overlaps and they cannot be separated by commonly used separation techniques [Peeters et al., 2014].

As a result, the most adopted End-of-Life (EoL) treatments for flame retarded plastics in Europe are still incineration with energy recovery, co-combustion in cement kilns or landfilling [Vilaplana and Karlsson, 2008].

Laboratory tests have demonstrated that different FR plastics can be recycled and that the degree of deterioration of mechanical properties of the plastics and flame resistance strongly depends on the applied type of FR and stabilizer compounds [Cefic, 2006; Dawson and Landry, 2005; Moy, 2005; Imai et al., 2002].

Recently, advanced automated optical separation techniques have been developed to separate shredded plastic either based on plastic type, or on type of FR or on colour. Table 5.1 presents a summary of possible plastic sorting methods.

According to literature, Near Infra-Red analysis (NIR) is the most used spectroscopy method, although, it is not effective to sort black plastics (largely used both into packaging and EEE). A study from [WRAP, 2011] explored four possible approaches to enable automated sorting of black plastic packaging, as: 1) use of alternative spectroscopic techniques, 2) physical sorting methods, 3) addition of detectable markers and 4) the development of alternative colorants. WRAP (2011) concluded that only the alternative colorant technique would allow sorting of black packaging with existing NIR based mixed plastics sorting facilities. Other methods (as Mid Infrared (MIR), photoacoustic spectroscopy, Raman spectroscopy) were found to work on a technical level but are not yet viable at commercial sorting speeds.

Finally sorting of different plastics can be performed based on manual disassembly. This technique is not cost-effective for low value plastics as e.g. packaging [WRAP, 2011], but can be technically and economically viable for high-quality technical plastics used in EEE [Peeters et al., 2014; Mathieux et al., 2008]. The efficiency of manual sorting is, however, dependant on the properness of plastic marking, values of recyclates and labour cost.

Several authors identified plastic markings in EEE as a relevant strategy to support plastic recycling following manual disassembly [Peeters et al., 2014]. Moreover, several criteria of plastic marking have been added in various environmental labelling schemes (e.g. criteria for the EU Ecolabel). Marking of plastic should follow standardised approach, as that proposed by ISO 11469 [ISO, 2000], and standards of the series ISO 1043.

Although numerous sorting and treatment processes exist for mixed post-consumer plastic waste, these processes generally produce insufficiently pure products and do not efficiently remove contaminants and hazardous materials. For this reason, the products often do not meet required industrial specifications and the use of these recyclates is hence limited to a small number of applications where quality is of lesser importance. On such purpose, current research is also focusing on the development of alternative processes to produce high-quality recyclates from complex waste mixtures. One example is represented by the "CreaSolv" process in which the target polymers are selectively dissolved from the plastic waste and precipitated, while contaminants and hazardous materials (including flame retardants) are effectively removed from the solution using special purification methods [CreaCycle, 2016]. The volume of solvents used is very small in relation to the treated plastic (<1%), because the process is run in a closed-circuit and routinely recycled. The process is suitable for recovering thermoplastics (ABS, PS, EPS, PA, PC, PLA, PVC, PET, PE, PP, and blends of these polymers) from complex post-consumer waste streams (WEEE, ELV, construction waste) and mixtures of plastics (packaging waste), whereas the relatively small volume of impurities is separated and concentrated. The CreaSolv process is currently run at pilot scale plant, with a capacity between 2,000 and 4,000 tonnes annually.

**Table 5.1**: Methods for plastic sorting (adapted from [Peeters et al., 2014; EFRA, 2013; Masoumi et al, 2012; WRAP, 2011; Elo et. al, 2009])

| Method | Functioning | Efficiency |
|---|---|---|
| Density separation | | |
| Density separation | Sink-float techniques | High efficiency for sorting some plastics without additives (as HI-PS, PP, ABS, PC/ABS).<br>Contrasting values of the efficiency for sorting plastics with phosphorous based FR (HIPS/PPE and PC/ABS). Not applicable for brominated FR plastics. |
| Optical separation | | |
| Near Infra-Red analysis (NIR) spectroscopy | To sort coloured resins composed of different plastics. Diffuse reflection measurements are made in the NIR region to capture distinct spectral differences resulting from the unique polymer compositions. | Reliable separation and sorting PET, HDPE, PVC, PP and PS.<br>Not applicable to sort black plastics |
| Mid-infrared (MIR) spectroscopy | to capture distinct spectral differences resulting from the unique polymer compositions. | MIR is recommended for identification of some black plastics (e.g. in the automotive sector), although there are difficulties for industrial applications and lack of robustness of the equipment, as:<br>- The time of detection is at least in the order of 1 second, which is slower than with NIR<br>- computational problems of the system (due to the large number of peaks in the mid infrared region) |
| Dual Energy X-Ray Transmission (DE-XRT) | It makes use of a dual energy x-ray line scan sensor, which generates images of the transmitted x-rays. It allows for rapid approximation of atomic number range, which is utilised to evaluate the plastic composition. | According to pilot studies, it revealed to be effective in sorting plastics with brominated FR. |
| X-Ray Fluorescence (XRF) spectroscopy | The systems reject all particles which are analysed to have a bromine concentration above 1000 ppm. | It is used to commercially to detect and sort PVC containers.<br>The purity of non-BrFR plastics of the output fraction was always above 95%. Efficiency is largely depending on the belt speed.<br>Few data available on efficiency of sorting brominated-FR plastics.<br>However, it is difficult to quantify elements of low atomic number by this technique. PE, PP, PET and most other common polymers contain only the low atomic number elements (H, C and O) and cannot be differentiated using XRF. |
| Visible light optical separation | Automated colour sorter uses a high resolution camera and based on the RGB array of all particles a blasting valve selectively opens to blow out particles with the desired colour. | Efficiency in separating white plastics from coloured ones is around 95% - 96%. |
| Laser-induced breakdown (laser-induced plasma) spectroscopy | Plasma is generated within nano-seconds (ns) of the laser pulse. The emissions are collected and analysed then the detecting channel is cleared for the next sample. | Identification and calculation time are believed to be short, but the overall response time is not known, as there are no commercial systems available yet.<br>Surface coatings and labels will likely affect the results, as it is only the sample surface that is measured |

| Method | Functioning | Efficiency |
|---|---|---|
| Raman spectroscopy | Emission technique that does not rely on the measurement of absorbed or reflected radiation. A laser operating in the near infrared or visible region is used to excite the material, producing a characteristic emission spectrum in the infrared region through the Raman scattering effect. | Raman spectroscopy is a potential method for sorting black post-consumer packaging, subject to a commercially viable detection system becoming available.<br>Some electronic companies declared the use of the method to sort black plastics. However, black pigmented samples cannot normally be measured, due to high surface absorption of the incident laser pulse and extra fluorescence from the carbon black. Recent advances have been made to solve this problem. |
| Photoacoustic spectroscopy | laser radiation is pulsed at an audible frequency, resulting in a sound proportional to the intensity of radiation<br>absorption | The colour and surface condition of the article will not affect the photoacoustic response.<br>It has been tested in recycling plants for automotive and electronic waste sorting. It is not known if the robustness and response time of the technique is suitable for use in recycling plants for post-consumer plastics. |
| Manual separation | | |
| Manual disassembly | Separation based on manual disassembly. The sorting is performed according to plastic marking and/or Fourier Transform Infra- Red (FTIR) scanner. | Generally applicable to all types of plastics. Efficiency relate to the correctness of the plastic marking and/or the precision of the scanner. |

## 5.3 Strategies to improve the recyclability of plastics

In 2013 the European Commission published the Green Paper on a European Strategy on Plastic Waste in the Environment [EC, 2013b]. The purpose of the document was to launch a broad reflection on possible responses to the public policy challenges posed by plastic waste which are at present not specifically addressed in EU waste legislation.

The Green Paper proposed some specific questions on how to promote plastic reusability / recyclability / recoverability (RRR) as:

- Which changes to the chemical design of plastics could improve their recyclability?
- How could information on the chemical content of plastics be made available to all actors in the waste recycling chain?
- Could new rules on eco-design be of help in achieving increased reusability and durability of plastic products?

In the response to this a study was financed to collect feedback from several stakeholders [BIO, 2013]. Labelling of plastics in a unified way was recognised as an option that allows plastics to be easily identified [BIO, 2013] and as an effective way to make information on the chemical content of plastics available to all actors in the waste recycling chain [EEB, 2013]. Moreover, it was suggested that "*a plastic type registry could be introduced to standardize a common treatment using markings of plastics or data sheet, bill of materials. It should be at least clearly marked that those plastics that contain additives and toxics so that they can be easily separated from "clean" plastics so that safe recycling can increase the margin and more expensive one will have an incentive to phase out toxics and additives to join the "good group*" [EEB, 2013].

According to the study, sustainable design has to be achieved by the gradual phasing out of hazardous additives and the avoidance of substances that make recycling more difficult [BIO, 2013]. Other recommendations were about the use of single type of polymers and the avoidance of multi-layer plastics when possible.

Some of the strategies proposed to improve RRR of plastics are [BIO, 2013]:

- Marked based instruments (taxes or incentives)
- Extended producer responsibility
- Raising consumer awareness
- Material safety data sheet
- Stringent requirements on the composition of plastics
- Requirement on recycled content of plastic parts
- Requirements for marking/labelling of products and improvement of their dismantlability.

On this last point EEB observed that "The Ecodesign Directive must focus more on fostering reuse, recycling and making products reparable and longer lasting. This could be done in priority for products with quick turn over and containing critical material that have a high environmental impact, such as ICT. As regard plastic material, requirements for marking of plastic, disassembly of plastic part above 100 cm2, recyclability of plastic without need for prior costly de-pollution should be set" [EEB, 2013].

## 5.4 Plastic marking

Marking can facilitate the sorting of plastics and thus facilitate recycling. "Although plastics are often sorted using automated sorting processes which are not related to marking, there are still recyclers that do take the marks into account. It is believed that these enterprises would benefit from a systematic strategy to use plastic marking in EU product policy" [BIO, 2014].

The relevance of plastic marking has been recognised by several manufacturers, which used to develop guidelines to promote the proper plastic marking of plastic parts in their products. For example, Bombardier Transportation is committed to mark polymeric components weighing in excess of 100 grams in line with ISO 11469 [ISO, 2000] and associated standards. This ensures that polymeric components can be efficiently identified, separated and processed for recycling at end-of-life [Bombardier, 2010]. "*In order to maximize the intrinsic value of plastic materials, they must be easily identified and then separated at end-of-life according to their material type and chemical structure. Attempting to recycle poorly separated polymer or rubber materials at end-of-life will result in a poor quality material, which has low or zero monetary worth and properties that make it suitable for only the most undemanding of applications. Through ensuring that materials are properly separated prior to recycling, the mechanical and aesthetic properties of the resulting recycled material can be maximized, thus dramatically increasing the value and suitability of the recycled material for future applications. […] To identify all of the various plastics, rubbers and thermoplastic elastomers without the aid of markings would be prohibitively cost intensive and* *therefore must be avoided. In many instances, plastics, rubbers and thermoplastic elastomers may contain additives such as fillers, plasticizers and flame retardants. Therefore, the correct marking may consist of abbreviated terms for the base material(s) plus symbols for the additives described above*" [Bombardier, 2010].

According to ISO 11469, the marking of plastic parts should follow the scheme described in Figure 5.2. The standard also states that markings are to be made by one of the following methods:

- during moulding by having the appropriate symbol included in the mould design.
- by embossing, by melt imprinting or by other legible and indelible marking of the polymer (used e.g. for extruded plastics).

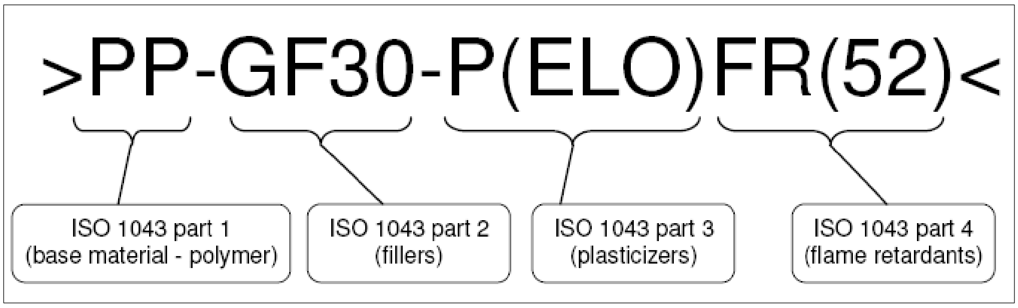


**Figure 5.2**. Plastic marking according to ISO11469 (adapted from [Bombardier, 2010])

The list of ISO standards for plastic marking is shown in Table 5.2.

However, additional guidance is also necessary for aspects not specified by the standard as:

- parts to be marked;

- dimensions of marking;

- font to be used;

- location and visibility;

- additional characteristics (e.g. being indelible).

The ISO 11469 intentionally does not provide details on this assuming that: "*Precise details of the marking, e.g. the minimum size of the item to be marked, the size of the lettering, the appropriate location of the marking, are subject to agreement between the manufacturer and the user*".

**Table 5.2**. Standards for plastic marking of environmental criteria on plastic marking

| Standard n° | Title |
|---|---|
| ISO 11649 | Plastics -- Generic identification and marking of plastics products |
| ISO 1043-1 | Plastics -- Symbols and abbreviated terms -- Part 1: Basic polymers and their special characteristics |
| ISO 1043-2 | Plastics -- Symbols and abbreviated terms -- Part 2: Fillers and reinforcing materials |
| ISO 1043-3 | Plastics -- Symbols and abbreviated terms -- Part 3: Plasticizers |
| ISO 1043-4 | Plastics -- Symbols and abbreviated terms -- Part 4: Flame retardants |
| ISO 1629 | Rubber and latices -- Nomenclature |
| ISO 18064 | Thermoplastic elastomers -- Nomenclature and abbreviated terms |

Marking of plastics in accordance with ISO 11469 can also be coupled with other appropriate identification codes (e.g. the "Resin identification code" for plastics packaging materials [ASTM, 2013]), as suggested by the British Plastics Federation [BPF, 2015].

### 5.4.1 Plastic marking in environmental labelling schemes

The previous section highlighted the need of additional guidance for a systematised plastic marking. On such purpose, criteria for plastic marking have been introduced by several environmental labelling schemes to promote the recyclability of plastics (Table 5.3). The structure of the criteria is very similar in all the observed criteria (aligned to the ISO 11469 standard), although some additional remarks are added as:

- minimum dimension of parts to be marked (generally 25 g) or minimum surface (generally 200 $mm^2$);

- nomenclature (according to ISO 1043);

- exemptions (for technical or aesthetic reasons)

No detail is instead provided in the ecolabelling criteria about dimensions, positioning and minimum dimensions of the marking.

**Table 5.3**. Examples of environmental criteria on plastic marking

| Labelling scheme | Criteria | Reference |
|---|---|---|
| IEEE 1680.3 | Product criterion: Plastic parts > 25 g shall be marked with a material code in accordance with the identification and marking requirements of ISO 11469 considering ISO 1043. Plastic parts on which the only sufficiently sized marking surface is also a necessary functional surface (e.g., a button face), parts with less than 200 $mm^2$ of plane surface, parts that the material code is unable to be moulded into the part for aesthetic reasons (e.g., transparent part on front panel), printed circuit boards, labels, cables, connectors, electronic components, optical components, ESD components, and EMI components are excluded from this requirement. | 1680.3-2012 - IEEE Standard for Environmental Assessment of Televisions |
| EU Ecolabel | Plastic parts shall be of one polymer or be of compatible polymers for recycling and have the relevant ISO 11469 marking if greater than 25 g in mass. | Commission Decision of 12 March 2009 establishing the revised ecological criteria for the award of the Community Eco-label to televisions (2009/300/EC) |
| Nordic Ecolabel | Plastic parts > 25 g must carry permanent labelling specifying the material in accordance with the latest versions of ISO 11469 and ISO 1043, sections 1 to 4.<br>This requirement does not apply to extruded plastics or light conductors in flat displays. Plastic parts covering a flat surface of less than 200 $mm^2$ are also exempted from this requirement. | Nordic Ecolabelling of Computers.<br>Version 7.1. October 2016 |
| Der Blau Engel | Plastic parts with a mass > 25 g that have a flat surface of at least 200 $mm^2$must be permanently labelled in accordance with ISO 11469. | Basic Criteria for Award of the environmental Label. Digital Projectors Edition April 2014 |

Examples of requirements have been enforced also into European policies. For example, the ELV Directive (2000/53/EC) and the supporting decision (2003/138/EC) established that [EC, 2000]:

> For the labelling and identification of vehicle plastic components and materials having a weight of more than 100 grams, the following nomenclature applies:
>
> — ISO 1043-1 Plastics — symbols and abbreviated terms. Part 1: Basic polymers and their special characteristics.
>
> — ISO 1043-2 Plastics — symbols and abbreviated terms. Part 2: Fillers and reinforcing materials.
>
> — ISO 11469 Plastics — Generic identification and marking of plastic products.
>
> For the labelling and identification of vehicle elastomer components and materials having a weight of more than 200 grams, the following nomenclature applies:
>
> — ISO 1629 Rubbers and latices — Nomenclature. This shall not apply to the labelling of tyres.

Although the plastic marking is largely enforced on a voluntary basis by the majority of EEE manufacturers, in some cases the efficiency of such practice is criticised, as for example [DE, 2014]:

> "Most display makers currently mark their plastic parts >100 g following the ISO 1043-1 (polymer type) and ISO 1043-4 (FR code) on a voluntarily basis. From communications with recyclers we learned that they do not see an added value in the marking of plastics, as recycling technology development is moving towards high speed processes which allow automated detection and segregation of the plastic material. While older manual recycling technologies may still be in use, it is expected that they will soon become obsolete and unable to compete with modern efficient treatment plants responsible for the majority of WEEE processing within the ten years a display product would take to become WEEE. Detailed marking information is therefore not used or necessary for WEEE recycling purposes".

However, different evidences have been observed concerning plastic marking and recycling:

- Various automated plastic sorting systems have been developed (or are under study). However, their effectiveness is still not proved in some cases (e.g. black plastics or plastic with flame retardants)
- Changes in technologies did not occur as fast as expected in the last decade and plastic sorting is still occurring mainly based on density separation.
- Several recyclers highlighted the relevance of plastic marking for disassembly processes ([Peeters et al., 2014; Ardente and Mathieux, 2014])
- Plastic marking generally implies low costs (mainly related to the mould design) (Ardente and Mathieux, 2012b).

Concerning alternative marking of plastics, Elo et al. (2009) discussed the use of fluorescent markers, i.e. the use of fluorescent substances into plastics to mark the plastic type. Plastics could be then sorted using a ultra-violet sensor combined with conveyors and a pneumatic system. There are pneumatic systems that have the capability to sort out two different materials from the main flow at one pneumatic station. The efficiency of such devices for different plastic types was, however, not explored. Furthermore, the system is affected by some limitations as it requires that all the plastics are marked in a predefined way and that the markers can be interpreted independently from the orientation of the material in the conveyor [Elo et al., 2009].

### 5.4.2 Efficiency of plastic marking

An assessment of how ISO 11469 is actually being applied during the waste handling and treatment has been made by Masanet et al. (2002). This study assessed the effectiveness of the ISO 11469 and other designs for recycling. The study showed that when the plastic parts were manually sorted, the use of ISO labels were in fact an effective strategy for improving the recyclability of plastic parts, but the study also indicated that up to 20% of the ISO labels were incorrect. For automatic sorting systems the ISO labels had no effect as this sort according to the plastic's mechanical, optical and electrostatic properties. Hence, the effectiveness of the requirement on marking of plastic parts will depend on the sorting systems and in worst case it will not have any effect on recyclability and thereby resource efficiency.

Masanet et al. (2002) also identified additional criteria, complementary to plastic marking, which can improve recyclability of plastics, as:

- Using only one type of polymer for all large plastic parts: using only one type of polymer for all large plastic parts on a computer is intended to increase the quantities of that polymer for recycling. When sufficient volumes of a given polymer are present in a batch of computer plastics, it is possible to target single polymer recycling applications.
- Limiting the use of paint: When painted plastics are recycled, paints may remain as inclusions that can reduce the mechanical properties and aesthetic value of recycled plastics. Limiting the amount of paint to 1% of the overall part mass is designed to minimize the potential for these deleterious effects.
- Avoiding moulded-in or glued-on metal parts: before a plastic component can be recycled, all attached metal parts must first be removed. If a metal part cannot be removed easily, it can require extra labour and can thus make plastics recycling less economically viable.

Interestingly, various authors also encountered that a large number of plastic marking they analysed (up to 20% according to Masanet et al. (2002), up to 50% according to Peeters et al. (2014)) were incorrect. It was suggested that these errors are likely due to substitutions of different plastics at the factory or to the use of old moulding dies to make new plastic parts.

These analyses show that it is important to periodically ensure that markings are accurate. This check can be performed by manufacturers themselves (performed on their production lines or on their suppliers) or alternatively a check performed by market surveillance authorities, if requirements are to be implemented in the context of mandatory policies such as the Ecodesign Directive.

## 5.5 Potential requirements on plastic marking in product policies

Previous sections have concluded that an effective and comprehensive way for sorting plastics containing flame retardants is still missing. Technologies for plastic sorting did not evolve sensibly in the last decade, although some promising technologies are under study/development.

As highlighted by several authors, a systematic and reliable plastic marking is a potential strategy for the improvement of recyclability of plastic part. However, it is difficult to quantify the potential environmental benefits of plastic marking due to uncertainties in the evolution of plastic sorting technologies.

Plastic marking can also be used to identify potential toxic additives, as some flame retardants, used as additive in plastic parts. Moreover, the marking of plastics is already a well-established practice within manufacturers of EEE and also costs related to plastic marking are generally low.

Plastic marking has been standardised by ISO. However, the analysis has shown that:

- there is a general lack of additional guidance for some specific aspects of the marking;

- there are potential limits of plastic marking due to e.g. wrong marking of the parts and lack of verification of correctness of marking.

Various environmental labelling schemes introduced criteria to promote the marking of plastic parts and its verification. However, these criteria are adopted only by pro-active companies under a voluntary approach. Requirements on plastic marking could be therefore enforced via some mandatory requirements into EU policies. On such purpose, a recent preparatory study suggested to address this issue by a horizontal measure on marking of plastics [BIO, 2014]. Mandatory requirements for plastic marking, together with other potential requirements (e.g. on the use of post-consumer recycled plastics, the provision of information, requirement of design for dismantling), could improve the reliability of marking and allow a more efficient separation and recycling of plastic parts.

An example of generic requirement on plastic marking is presented.

**Requirement on marking of plastic parts**[22]

Plastic parts heavier than *X* g,

1. Shall be marked by specifying the type of plastic using the symbols as specified in standards EN 11469. The marking shall be legible.

Plastic parts in the following circumstances are exempt from marking requirements:

i. the marking is not possible because of the shape or size;
ii. the marking would impact on the performance or functionality of the plastic part;
iii. marking is technically not possible because of the molding method.

For the following plastic parts no marking is required:

(1) packaging, tape and stretch wraps;
(2) labels, wiring and cables;
(3) [list of *other exempted parts, based on the specific product groups, as for example,* PCB assemblies].

2. If flame retardants are present, they shall be marked using the symbols as specified in standard EN 1043:

**>x-FR-y<**

where:

x= plastic polymer

FR = flame retardant

y= type of the flame retardant coding

The model shall be considered to comply with the requirements, if all plastic parts of the product heavier than X g, other than those exempted, are marked with the proper symbols. Models with plastic parts heavier than X g (other than [list of *exempted parts*]) containing flame retardants shall be considered to comply with the requirements if marked with the proper symbols for flame retardant. For exempted plastic parts, the market surveillance authority shall check that a justification is provided by the manufacturers in the end-of-life documentation.

Concerning the structure of the requirement it is considered that:

- not all of the plastic parts can be marked (e.g. some optical plastic parts made in some electr(on)ic equipment). A list of components exempted for technical reasons should be provided.

[22] This generic requirement has been built on the basis of the analysis performed for the revision of material efficiency requirements for the Ecodesign of electronic displays and the revision of material efficiency criteria for the EU Ecolabel for computers and televisions.

- plastic marking should apply to parts with a minimum weight (e.g. 25 g), having these are parts an higher interest in being recycled.

- marking of plastics should include the type of polymer and the content of flame retardants, being this the key information needed to sort plastics and to recognise potential hazardous substances.

- the marking could include additional information on the content of other additives. This is based on a voluntary approach, due to potential difficulties of manufacturers in providing such information (including potential confidentiality issues and availability of information).

Moreover, because alternative solutions exist and are already implemented by some manufacturers, some incentives to reward design efforts in this area could be proposed. For example, additional information could be provided by manufacturers e.g. on the composition of plastic parts and by calculating/declaring specific index on plastics as e.g. the "Flame retardant in plastic parts" index. This index can be calculated as following:

***Formula 16:*** $$FR_{plastic\ parts} = \frac{m_{plastic-flame-retardant}}{m_{plastic}} \quad [\%]$$

Where:

- $FR_{plastic\ parts}$ = "Flame retardant in plastic parts" index [%]
- $m_{plastic\text{-}flame\text{-}retardant}$ = *Total m*ass of the plastic parts heavier than X [g] contained in the products[23] that contain flame retardant(s)
- $m_{plastic}$ = Total mass of plastic parts heavier than X [g] contained in the product[24]

This index aims at:

- detailing plastic parts that contains flame retardants (including mass and type of plastic parts; mass and type of flame retardants)

- calculating the percentage of plastic parts in the product that do not contain flame retardants

- promoting products that use less quantities of flame retardants.

An example of requirement on the provision of information on plastic parts based on the $FR_{plastic\ parts}$ index is following presented.

[23] Excluding exempted plastic parts.
[24] Excluding exempted plastic parts.

**Requirement on the provision of End of life information on plastic parts containing flame retardants**[25]

if plastic parts (excluding the PCB assemblies) containing flame retardants are used, manufacturers should provide documentation in the format of the following table.

Table I - 'Flame retardant in plastic parts' index calculation table.

(All masses shall be expressed in grams)

| Brand name and Product family: | | | |
|---|---|---|---|
| Part reference | Polymer (EN 1043-1 code) | Flame retardant (EN 1043-4 code) | Total mass for every polymer/FR combination (g) |
| Reference $_{(1)}$ | … | … | $m_{(1)}$ |
| Reference $_{(2)}$ | … | … | $m_{(2)}$ |
| … | … | … | … |
| Reference $_{(i)}$ | … | … | $m_{(i)}$ |
| A) Overall mass of plastic parts incorporated in the product (excluding printed circuit board assemblies and wirings) that contain flame retardants [g] | | | |
| B) Overall mass of plastic parts incorporated in the product (excluding printed circuit board assemblies and wiring) [g] | | | |
| C) Total mass of the product (excluding printed circuit board assemblies and wiring) [g] | | | |
| ***Indexes*** | | | |
| Ratio of plastic containing flame retardants on the total mass of plastic ('Flame retardant in plastic parts' index) (A / B) [%] | | | |
| Ratio of plastic containing flame retardants to the total mass of display (A / C) [%] | | | |

Manufactures shall make available on a website the documentation with the above information for the considered product family

[25] This generic requirement has been built on the basis of the analysis performed for the revision of material efficiency requirements for the Ecodesign of electronic displays.

# 6 Conclusion

The report presented the main recent revisions of the REAPro method, based on case-studies applications in the period 2013-2016. Revisions have also been based on comments from different stakeholders that have been contacted during these years.

In particular, this revision process regarded:

- the development of new indexes, as the ones concerning the assessment of reused components in remanufacturers products or the "Flame retardant in plastic parts" index. The former has been developed to couple with a gap identified in the REPro method, not addressing sufficiently reused components. The latter has been developed to monitor the content of flame retardants in plastics, which are one of the major barriers in the recycling of plastics in WEEE, as recurrently reported by recyclers.

- the revision of previous indexes, as the "Recyclability benefit rate" in order to clearly separate, in both the numerator and the denominator, the envrionmental benefits due to the production of secondary raw materials from the impacts due to the WEEE treatment and recycling.

- the improvement of the verifiability of previously developed requirements. This was the case of requirement on the design for disassembly based on number of disassembly steps and of the requirements on the dismatlabiltiy of key components.The report presented the evolution of the criteria on design for disassembly to grant the identification, access and extraction of key components for the product's recycling, including requirements on their fastening and the provision of relevant information for the end-of-life treatments. Recent criteria were developed taking into account the feasibility for Market Surveillance Authorities to verify them.

- the analysis of criticalities in plastic recycling. In particular, large number of different polymers, technological barriers for plastic sorting, content of additives (especially flame retardants), difficulties for the extraction of plastic parts, downcycling and low value of secondary materials are among the reasons of very low recycling rates for plastics in WEEE.

- finally the repors proposes the development of novel requirements, as those related to the reuse of components, the disassemblability of batteries, the marking of plastics and the content of flame retardants in products.

At the time of the report (December 2016) several of the requirements above mentioned have been integrated and discussed in various policy proposals, as the Ecodesign requirements for electronic displays, enterprise servers and commercial refrigerating appliances, and Ecolabel criteria for computers and displays.

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